APPLICATION FOR UNITED STATES PATENT

FOR

CLEARING OF VAPOR LOCK IN A MICROCHANNEL COOLING SUBSYSTEM

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Field of the Invention

The present invention relates to the field of integrated circuits, and, more particularly, to the clearing of vapor lock within microchannels of microchannel cooling subsystems.

Background of Invention

A microelectronic package comprises a microelectronic die electrically interconnected with a carrier substrate, and one or more other components, such as electrical interconnects, an integrated heat spreader, a heat sink, among others. An example of a microelectronic package is an integrated circuit microprocessor.

A microelectronic die comprises a plurality of interconnected microcircuits to perform electronic circuit functions. It generates heat as a result of the electrical activity of the microcircuits. In order to minimize the damaging effects of heat, passive and active thermal management devices are used. Such thermal management devices include heat sinks, heat spreaders, and fans, among many others. There are limitations in the use of each type of device, and in many cases, the thermal management device is specifically designed for a particular microelectronic die and package design and intended operations.

Non-uniform power distribution across the microelectronic die results in local areas of high heat flux (hot spots) that must be mitigated. The thermal management device must be able to maintain these hot spots at or below a specified temperature. This is very difficult when the local heat flux can be 10-times the microelectronic die average. Current devices are overwhelmed and limited in their ability to mitigate these local high heat flux sources. The thermal resistance between the heat sink and/or heat spreader is not low enough to adequately provide the necessary thermal mitigation in a reasonably sized system.

Currently, the localized heat generation is dissipated away from the microelectronic die once the heat has diffused to the surface. An Integrated Heat Spreader (IHS), heat sink, and/or a fan coupled to the surface do not have a major effect on spreading heat at the local-level within the microelectronic die. As a result, high temperature gradients and high-localized temperatures will continue to exist using the external methods of cooling.

Liquid pumps, embedded or external to the die, and microchannel cooling subsystems can address the problem of dissipating localized heat generation away from the microelectronic die, however vapor blockage can occur in the microchannels disrupting the cooling.

Brief Description of Drawings

Figure 1 *is a functional view of a pumping mechanism coupled to a microchannel cooling subsystem, in accordance with one embodiment of the present invention;*

Figure 2 *is a functional view of a pumping mechanism coupled to a microchannel cooling system, in accordance with another embodiment of the present invention;*

Figure 3 illustrates a system having the microchannel cooling subsystem of **Fig. 1** in accordance with one embodiment.

Description

In the following detailed description, reference is made to the accompanying drawings which form a part hereof wherein like numerals designate like parts throughout, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

Apparatus and methods in accordance with embodiments of the present invention utilize active cooling technology to reduce thermal gradients and operating temperature of a microelectronic die.

Embodiments of cooling systems in accordance with the present invention are provided below. It is understood that these are provided as examples of various embodiments for practicing the present invention, but are not intended to limit the present invention thereto. Embodiments of a cooling system comprising cooling fluid with a turbulent or laminar flow to a microelectronic cooling subsystem (or cooling devices), in accordance with embodiments the present invention, may include a pump and a bubble generator.

Figure 1 is a functional view of a cooling system 1, in accordance with one embodiment of the invention. As illustrated, a pumping mechanism **100** is coupled to a microchannel cooling subsystem **200** to provide the microchannel cooling subsystem **200** with fluid flow **111**, and if needed, causing turbulence in the fluid inside the microchannels of the microchannel

cooling subsystem **200**, to e.g. assist in the clearing of vapor locks in the microchannels (not shown) and increase the total rate of heat transfer from the microchannels. Turbulence may also be referred to as one or more higher pressure pulses.

For the embodiment, the pumping mechanism **100** comprises primary pump **110**, and auxiliary flow generator **120**, both coupled to an input of the microchannel cooling subsystem **200**. Pump **100** provides a primary fluid flow **111** of the cooling fluid to the microchannel cooling subsystem **200**. The fluid flow is provided by pump **110** at a first pressure level. Auxiliary flow generator **120** provides an auxiliary flow at a second pressure level to cause turbulence to the fluid inside the microchannels of the microchannel cooling subsystem, to contribute to the clearing of vapor locks inside the microchannels.

In various embodiments, pump **110** may be selected from pumps such as a vane pump, a piston pump, a diaphragm pump, electrokinetic (EK) pump (also known as a electroosmotic (EO) pump), or other suitable pumps; these pumps are listed as examples only and are not to be considered exhaustive.

For the embodiment, auxiliary flow generator **120** comprises a chamber **124** to contain a second fluid, an input port **121** coupled to the chamber **124** to accept the second fluid from an external source. Chamber **124** is coupled to output port **122**. Output port **122** may be larger than the input port **121**. Auxiliary flow generator **120** further comprises a heater **123** contained in chamber **124**. The heater **123** may be selectively activated for a period of time and rapidly vaporizes the contained fluid in the chamber **124** and generates one or more bubbles. In various embodiments, the heater **123** is activated by an active feedback controller **126**. The rapid expansion of the bubbles within the chamber **124** causes the second fluid in the

chamber to increase in pressure to the second pressure level (higher than the first pressure level). The second fluid in the chamber **124** is then forced out of said output port **122** and merged with fluid flow **111** causing the turbulence inside the microchannels to occur.

The timing of turning the heater **123** on and off is based upon the frequency in which the desired second pressure is created. Further, in various embodiments, in each instance, it is timed such that the bubble has a chance to collapse within the chamber **124** after displacing the second fluid, but before the bubble can travel out of the output port **122** and merged into the fluid flow **111**. For the embodiments, since the output port **122** is larger than the input port **121**, a significantly higher volume of the second fluid may be pumped out of the output port than the input port.

As described earlier, the second fluid upon merging into the fluid flow **111** at the second pressure level creates turbulence in fluid flow **111** inside the microchannels of the microchannel cooling subsystem **200**. The system is designed such that the turbulence provides sufficient energy to dislodge vapor blockages. In various embodiments, it may be further designed such that the turbulence may also provide for wetting of the microchannels (not shown) contained in the microchannel cooling subsystem to assist in at least temporarily reducing the likelihood of formation of vapor blockages.

Accordingly, for the embodiment, auxiliary flow generator **120** may also be referred to as a bubble generator. In various embodiments, the microchannel cooling subsystem **200** comprises a cold plate **210,** which may have one or more microchannels (not shown), and is thermally coupled to a microelectronic die **220**.

Figure 2 illustrates cooling system 2, in accordance with another embodiment. The embodiment is substantially the same as the embodiment

of **Fig. 1**, except the input port of chamber **124** is specifically coupled to the output of pump **110**. In other words, the external source of the second fluid provided to chamber **124** is pump **110**. Stated another way, for this embodiment, a tributary flow is created from the main flow at an upstream point, and rejoined with the main flow at a downstream point. While flowing through the "tributary", the pressure of the fluid may be selectively changed at the desired points in time, as it flows through chamber **124**, by creating bubbles in the tributary flow, using e.g. heater **123**. As described earlier, in various embodiments, the arrangement is designed such that the bubbles will collapse prior to the portion of the fluid carrying the bubbles exit chamber **124**.

Upstream and downstream are characterized referencing the direction of the fluid flow towards the microchannel cooling subsystem **210**. They are used for ease of understanding, and are not to be read as limiting on the invention.

In various embodiments, the type of fluid employed, the flow rate, the nominal and increased pressure of the flow, the capacity of the heater, and so forth, are application dependent. That is, they are dependent on amount of heat generated by the heat source, the expected heat removal efficiency of the microchannel cooling subsystem **210**, the number of microchannels and so forth. The optimal parameters, i.e. nature of the fluid, flow rate, pressures, and so forth, may be empirically selected, based on the application.

In various embodiments, a number of cooling fluids may be used, including, but not limited to, deionized (DI) water. Because of its relatively low ionic conductivity, DI water (10^{-3} S/m) is particularly suitable as a working fluid to maintain a moderate thermodynamic efficiency.

In various embodiments, the cooling system may also be operated in either a single phase liquid or two-phase liquid/gas mode.

In other embodiments, either the microchannels or the entire self contained cooling system may be contained in other devices, including, but not limited to, a flat heat spreader and a heat sink. Embodiments having self-contained cooling systems can be used to retrofit pre-existing devices, or devices of a predetermined standard size. The microchannels may also be integrated with the microelectronic die package.

Figure 3 illustrates a system in accordance with one embodiment. As illustrated, for the embodiment, system **300** includes computing device **302** for processing data. Computing device includes a motherboard **304**. Motherboard **304** includes in particular an integrated circuit (IC) package **306**, a networking interface **308** coupled to a bus **310**. More specifically, central processing unit **306** is microchannel cooling subsystem **200** with pumping mechanism **100**.

Depending on the applications, system **300** may include other components, including but are not limited to a bus, volatile and non-volatile memory, a microprocessor, a chipset, mass storage (such as hard disk, compact disk (CD), digital versatile disk (DVD) and so forth), and so forth. In various embodiments, system **300** may be a personal digital assistant (PDA), a mobile phone, a tablet computing device, a laptop computing device, a desktop computing device, a set-top box, an entertainment control unit, a digital camera, a digital video recorder, a CD player, a DVD player, or other digital device of the like.

The pumping mechanism creating turbulence in a fluid flow in a microchannel cooling subsystem in embodiments in accordance with the present invention disclosed herein will likely enhance heat dissipation, and/or provide better wetting of the microchannels to reduce the likelihood of vapor lock, by dislodging the vapor locks. This will likely to have the effect of reducing the microelectronic die temperature and/or spreading the heat internally within the microelectronic die, depending on the layout of the microchannels. The benefits of reducing thermal gradients and lowering average microelectronic die operating temperature may include: reduction of thermal stresses that are a significant reliability issue and enhanced microelectronic die electrical performance.

Although specific embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations calculated to achieve the same purposes may be substituted for the specific embodiment shown and described without departing from the scope of the present invention. Those with skill in the art will readily appreciate that the present invention may be implemented in a very wide variety of embodiments. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.